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TECHNICAL REPORT NO. S 1006

PLANNING AND SCHEDULING JOBS ON A COMPUTER USING CPM

OPERATIONS RESEARCH BRANCH
OPERATIONS IMPROVEMENT DIVISION

May 1969

by Irwin F. Goodman

TACOM

MANAGEMENT AND DATA SYSTEMS DIRECTORATE

U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

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AD 11560

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ABSTRACT

This report presents by example the application of the critical path method (CPM) for the planning and scheduling of jobs on a computer. It provides a step by step preparation and analysis of a network representation of a computer system application. Also, included is a glossary of relevant terms and a fairly comprehensive bibliography on the subject of CPM/PERT and scheduling and sequencing.

FOREWORD

The author wishes to acknowledge Mr. Angelo Constance, ADP Computer Operations, for providing preliminary network representations of a few select computer system applications.

PLANNING AND SCHEDULING
JOBS ON A COMPUTER
USING CPM

TABLE OF CONTENTS

I. Introduction

This study, the planning and scheduling of jobs on computers using the critical path method was prompted by the need of routine file maintenance during the cyclic computer processing of an inventory management system. Concurrently, with the conduct of this study, preliminary network representations are being developed by the computer activity for select systems applications. The purpose of this report is to present by example the application of CPM for the planning and scheduling of jobs on a computer; thereby, providing the computer activity and higher management with an in-advance working example of CPM planning and scheduling. Based upon a preliminary network representation of one of the system applications, the MILSTRIP/MILSTRAP process, a further refined and modified network has been prepared for demonstrating the CPM techniques. It should be emphasized that the network used in this report has been prepared primarily to demonstrate CPM rather than describe a particular system application. Consequently, it has been distorted and somewhat simplified for the sake of demonstration.

II. Steps in the Critical Path Method Procedure

1. Define various computer jobs (activities).

2. Establish precedence relationship for various computer jobs (activities).

3. Prepare network diagram representation.

4. Estimate expected time to perform each activity in network.

5. Analyze network with CPM analysis techniques.

   a. Establish critical path(s).

   b. Determine earliest and latest start time, earliest and latest finish time, and float (slack) time for all activities, especially file maintenance jobs.

6. Interpret results.

7. Prepare a table showing for each activity the subsequent sequence time and activities that must immediately preceed it.

8. Establish several feasible alternative sequences for assigning and scheduling activities.

9. Evaluate alternative sequences.

III. Example of the Critical Path Method Procedure

a. Basic Data for CPM Network Representation (steps 1-2)

(1) Events by Number and Description

Event No.	Event Description	Immediately Preceding Event No's
1	Start Process	
6	Start Initialization of Process	1
9; 109; 209	Start Validation Process	6; 100; 200
12; 112; 212	Complete Validation Process	9; 109; 209
15; 115; 215	Start MRHSF Daily Process	12; 142, 112; 242, 212
18; 118; 218	Start TWOS XREF Edit Process	12; 112, 145; 212, 245
21; 121; 221	Start CHEF Process	12; 112, 148; 212, 248
33; 133; 224	Complete MRHSF Daily Process	15; 115; 215
36; 136; 236	Complete TWOS XREF Edit Process	18; 118; 218
39; 139; 239	Complete CHEF Process	21; 121; 221
54; 154; 254	Start MSP Process	33; 175, 133; 275, 233
57; 157; 257	Complete MSP Process	54; 154; 254
60; 160; 260	Start IMDR Process	57, 33; 157, 133; 257, 233
63; 163; 263	Start IMDR Process on Machine I	60; 160; 260
66; 166; 266	Start IMDR Process on Machine II	60; 160; 260
69; 169; 269	Complete IMDR Process on Machine I	63; 163; 263
72; 172; 272	Complete IMDR Process on Machine II	66; 166; 266
78; 178; 278	Complete IMDR Process	69, 72, 36, 39; 169, 172, 136, 139; 266, 272, 236, 239

III. Example of the Critical Path Method Procedure (cont...)

Event No.	Event Description	Immediately Proceding Event No's
99	Complete Initialization of Process	184
100; 200	Start 1st; 2nd Cycle	9; 284, 100
124; 224	Start MRHSF Daily Update Next Cycle	12; 112
127; 227	Start TWOS XREF Edit Update Next Cycle	12; 112
130; 230	Start CHEF Update Next Cycle	12; 112
142; 242	Complete MRHSF Daily Update Next Cycle	124; 224
145; 245	Complete TWOS XREF Edit Update Next Cycle	127; 227
148; 248	Complete CHEF Update Next Cycle	130; 230
151; 251	Start MSP Update Next Cycle	33; 133
175; 275	Complete MSP Update Next Cycle	151; 251
181; 281	Start TEF Update Next Cycle	78; 199
184; 284	Complete TEF Update Next Cycle	181; 281
199; 299	Complete 1st; 2nd Cycle	178; 278
999	End Process	299

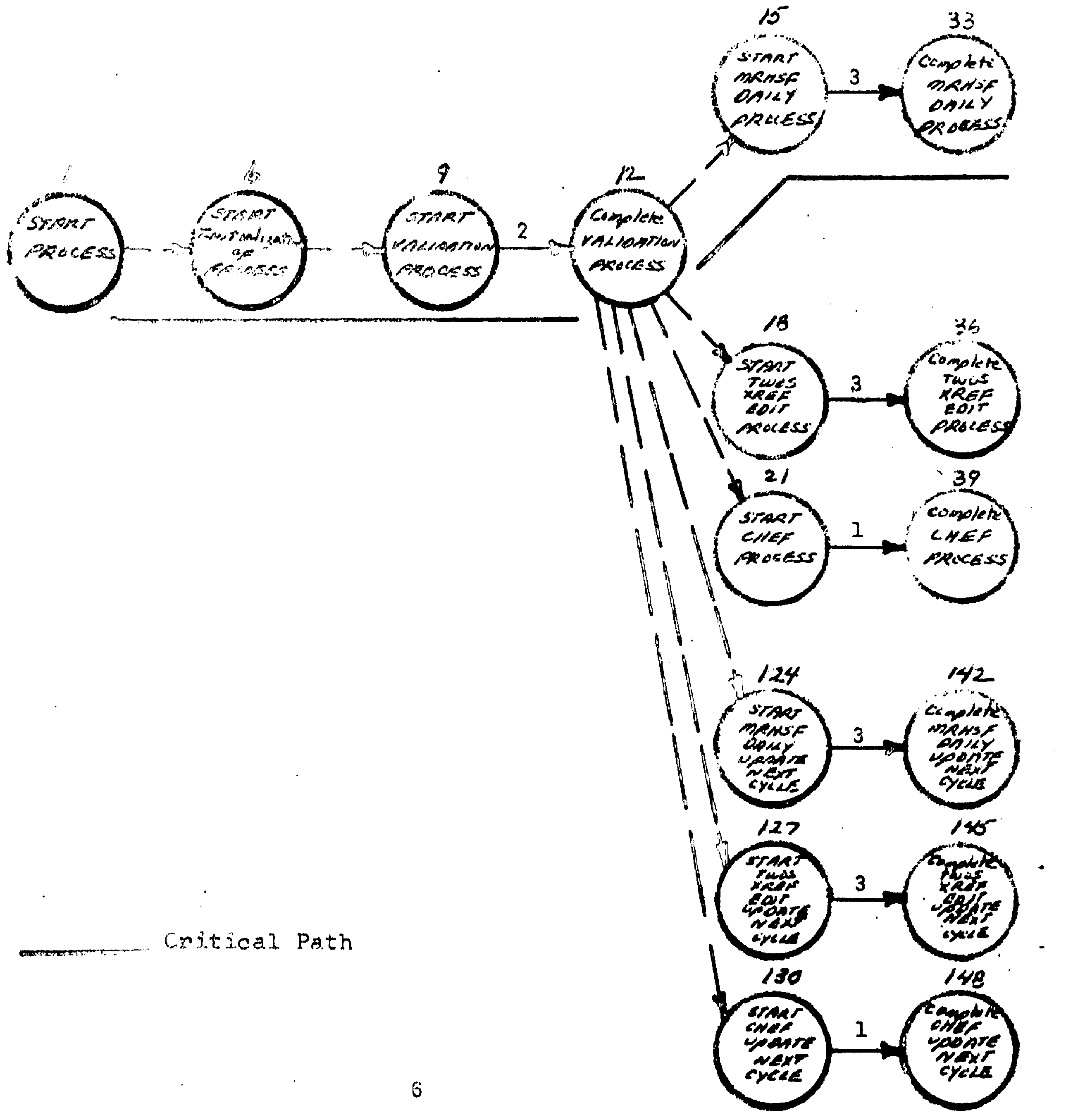
III. Example of the Critical Path Method Procedure (cont...)

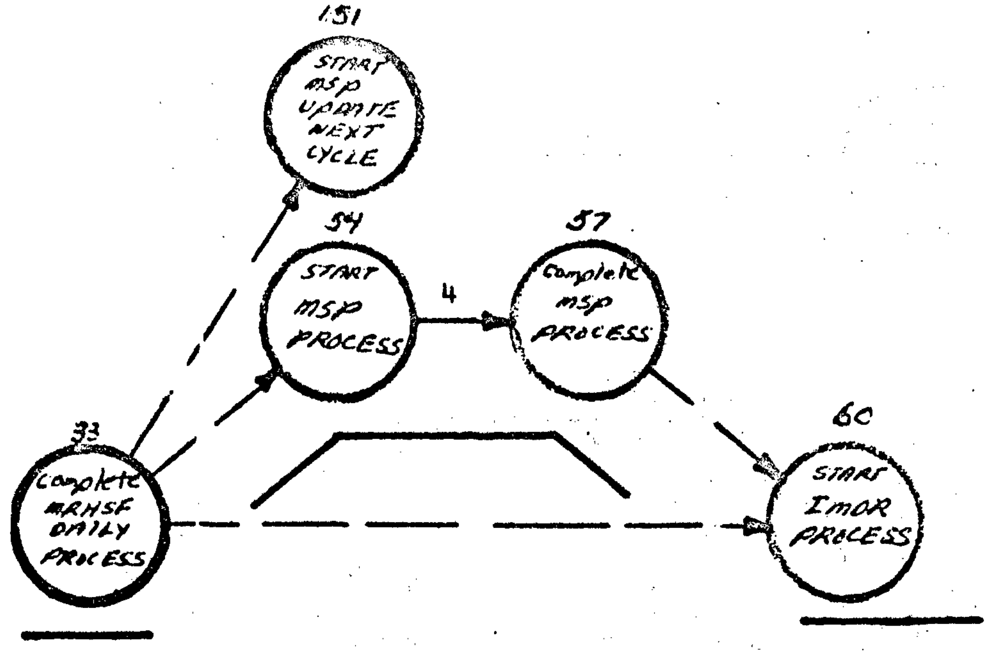
(2) Activity by Number, Description Duration and Immediately Preceding Activities (Steps 1, 2 and 7)

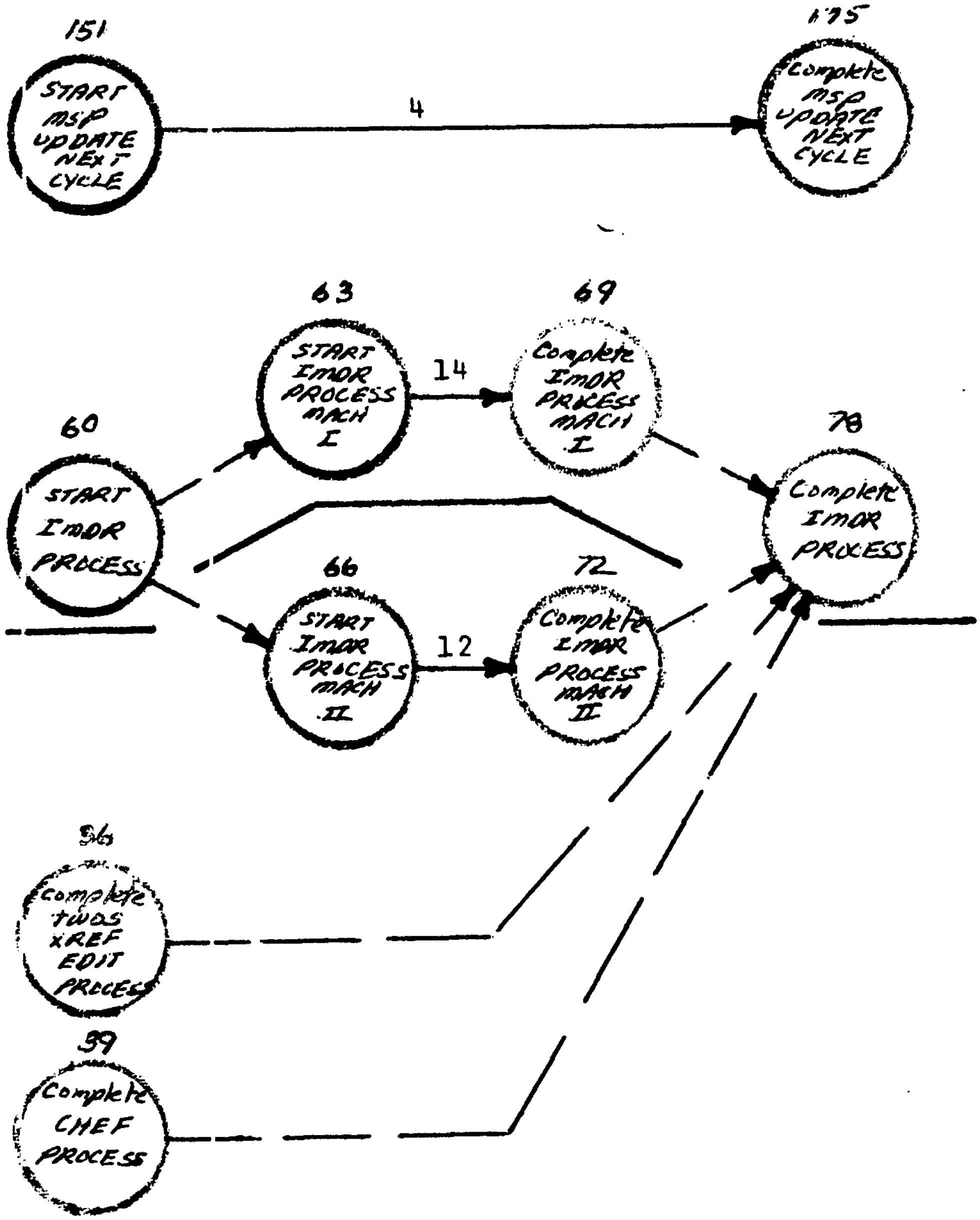
Activity No.	Activity Description	Activity Duration (Hours)	Immediately Preceding Activities
9-12; 109-112; 209-212	Validation Process	2	-; 181-184; 281-284, 100-200
15-33; 115-133; 215-233	MRHSF Daily Process	3	9-12; 124-142, 109-112; 224-242, 209-212
18-36; 118-136; 218-236	TWOS XREF Edit Process	3	9-12; 109-112, 127-145; 209-212, 227-245
21-39; 121-139; 221-239	CHEF Process	1	9-12; 109-112; 130-148; 209-212, 230-248
54-57; 154-157; 254-257	MSP Process	4	15-33; 115-133, 151-175; 215-233, 251-275
63-69; 163-169; 263-269	IMDR Process Machine I	14	54-57; 154-157; 254-257
66-72; 166-172; 266-272	IMDR Process Machine II	12	54-57; 154-157; 254-257
100-200	Time Restraint Between Cycle Starts	24	181-184
124-142; 224-242	MRHSF Daily Update Next Cycle	3	9-12; 109-112
127-145; 227-245	TWOS XREF Edit Update Next Cycle	3	9-12; 109-112
130-148; 230-248	CHEF Update Next Cycle	1	9-12; 109-112
151-175; 251-275	MSP Update Next Cycle	4	15-33; 115-133
181-184; 281-284	TEF Update Next Cycle	2	63-69, 66-72, 18-36, 21-39; 163-169, 166-172, 118-136, 121-139

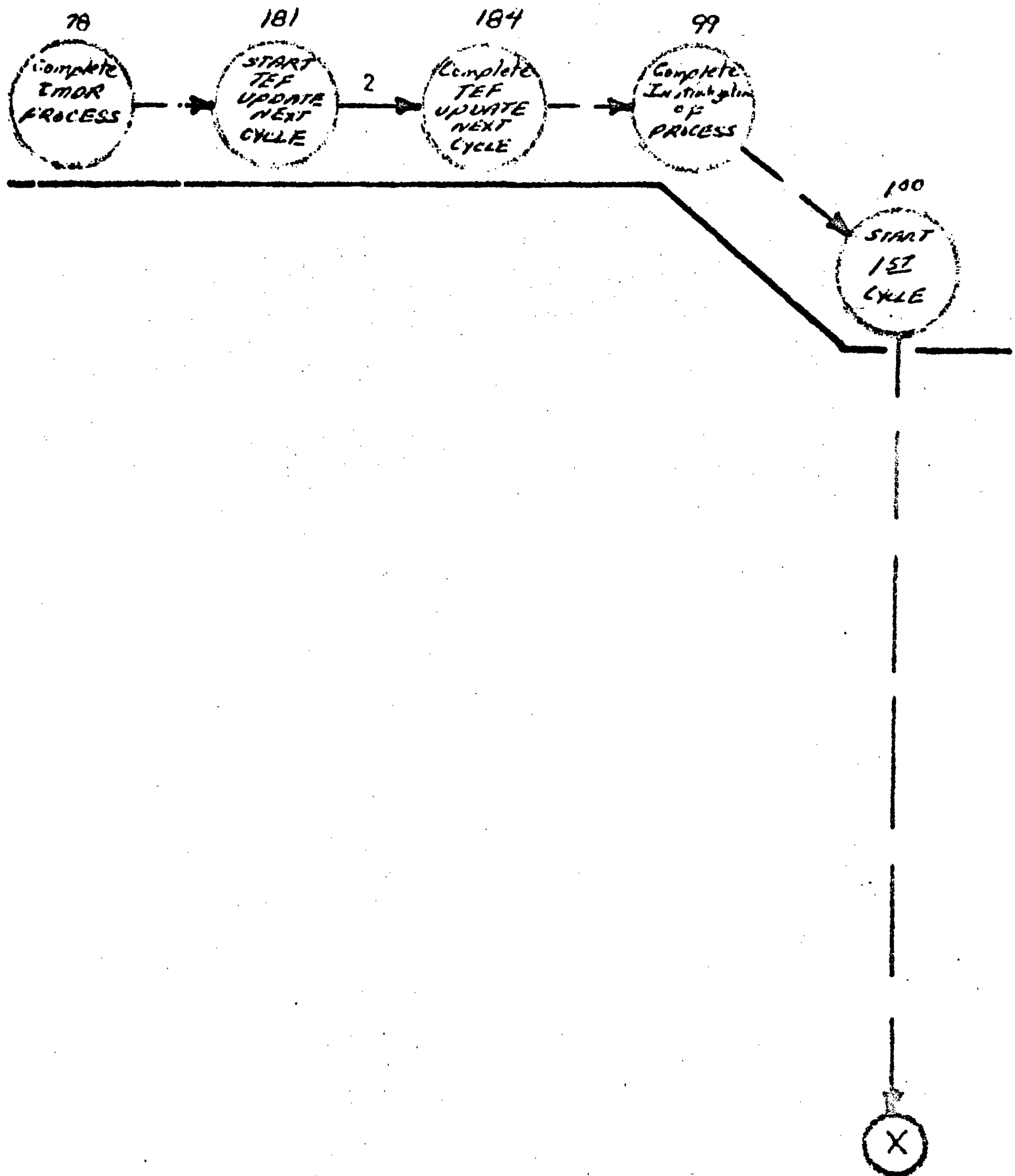
III. Example of the Critical Path Method Procedure (cont...)

b. Network Diagram Representation (Steps 3-5)

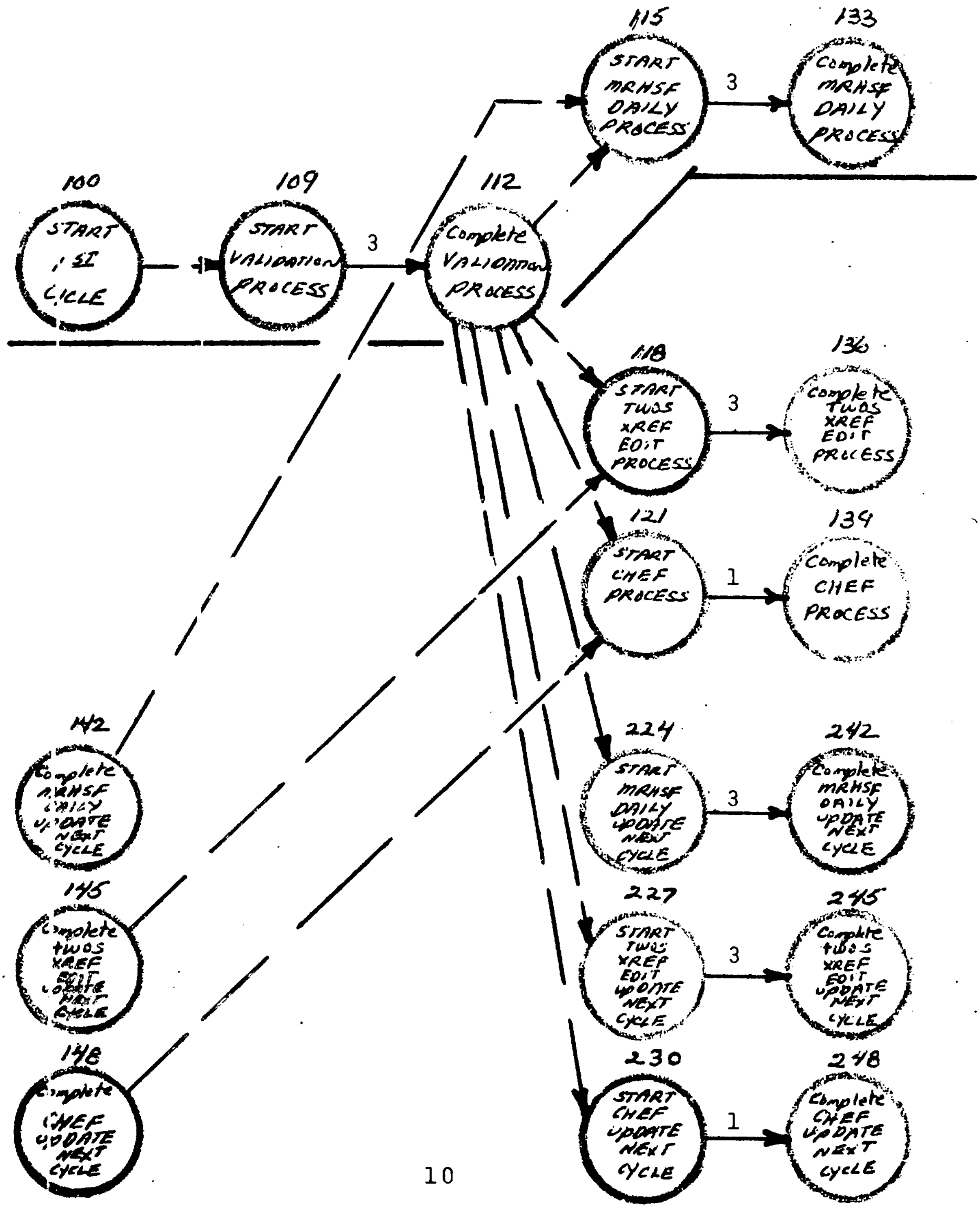



151
START
MSP
UPDATE
NEXT
CYCLE
54
START
MSP
PROCESS
4
57
Complete
MSP
PROCESS
60
START
IMOR
PROCESS
33
Complete
MRHSF
DAILY
PROCESS

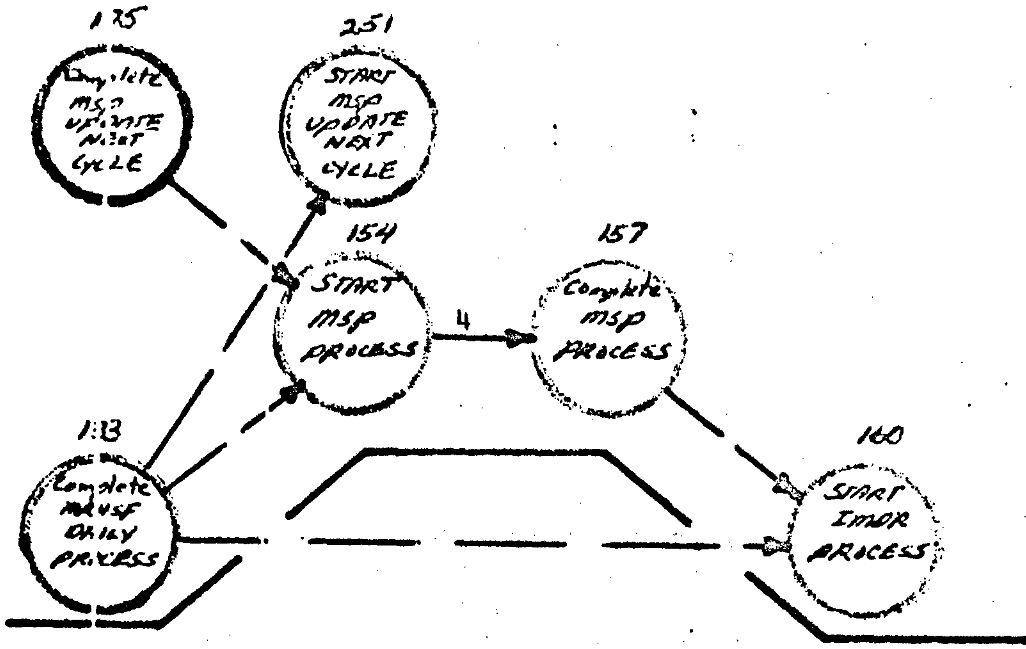

151
START MSP UPDATE NEXT CYCLE
4
175
Complete MSP UPDATE NEXT CYCLE
63
START IMOR PROCESS MACH I
14
69
Complete IMOR PROCESS MACH I
60
START IMOR PROCESS
78
Complete IMOR PROCESS
66
START IMOR PROCESS MACH II
12
72
Complete IMOR PROCESS MACH II
56
Complete TWOS XREF EDIT PROCESS
39
Complete CHEF PROCESS

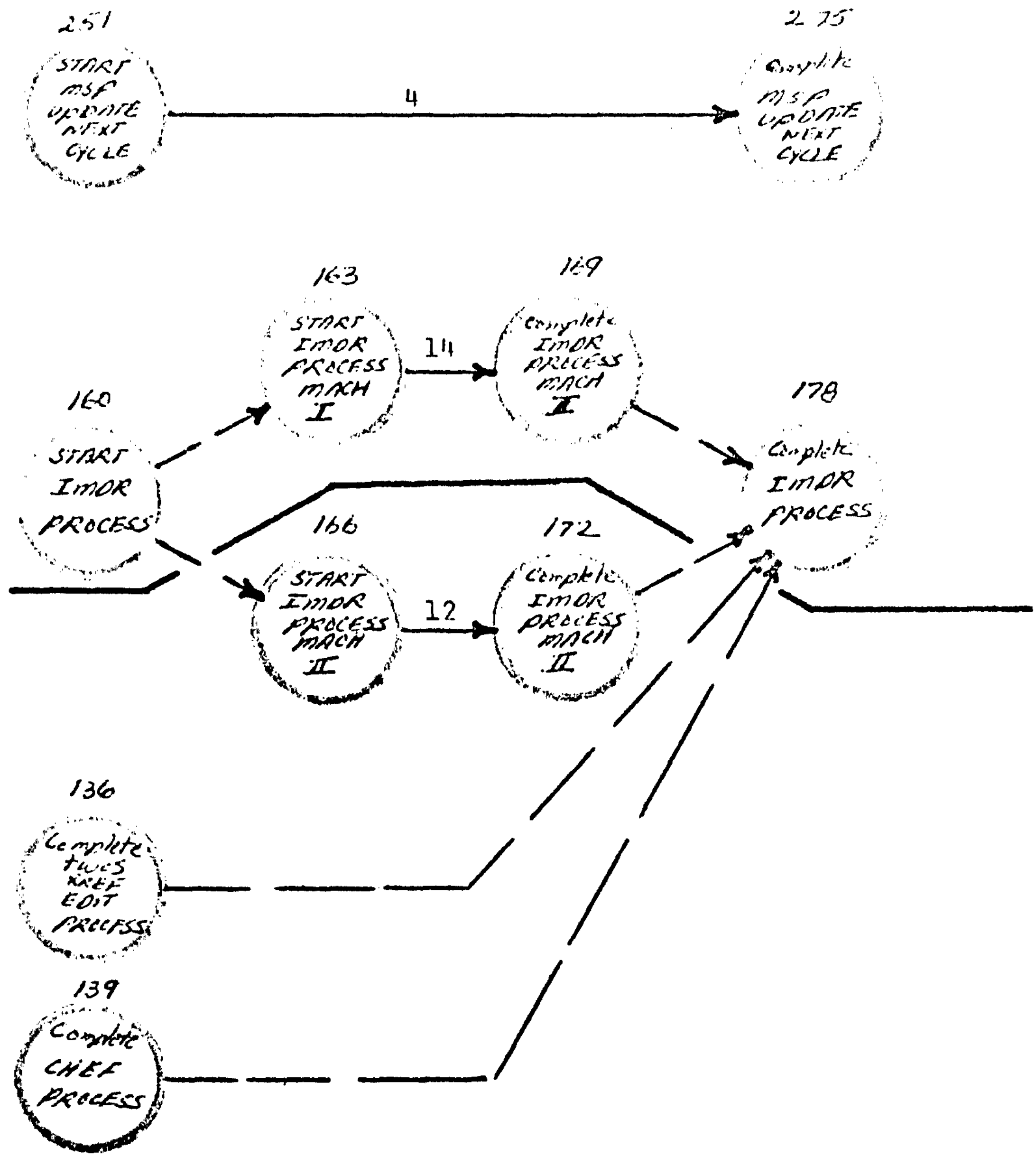


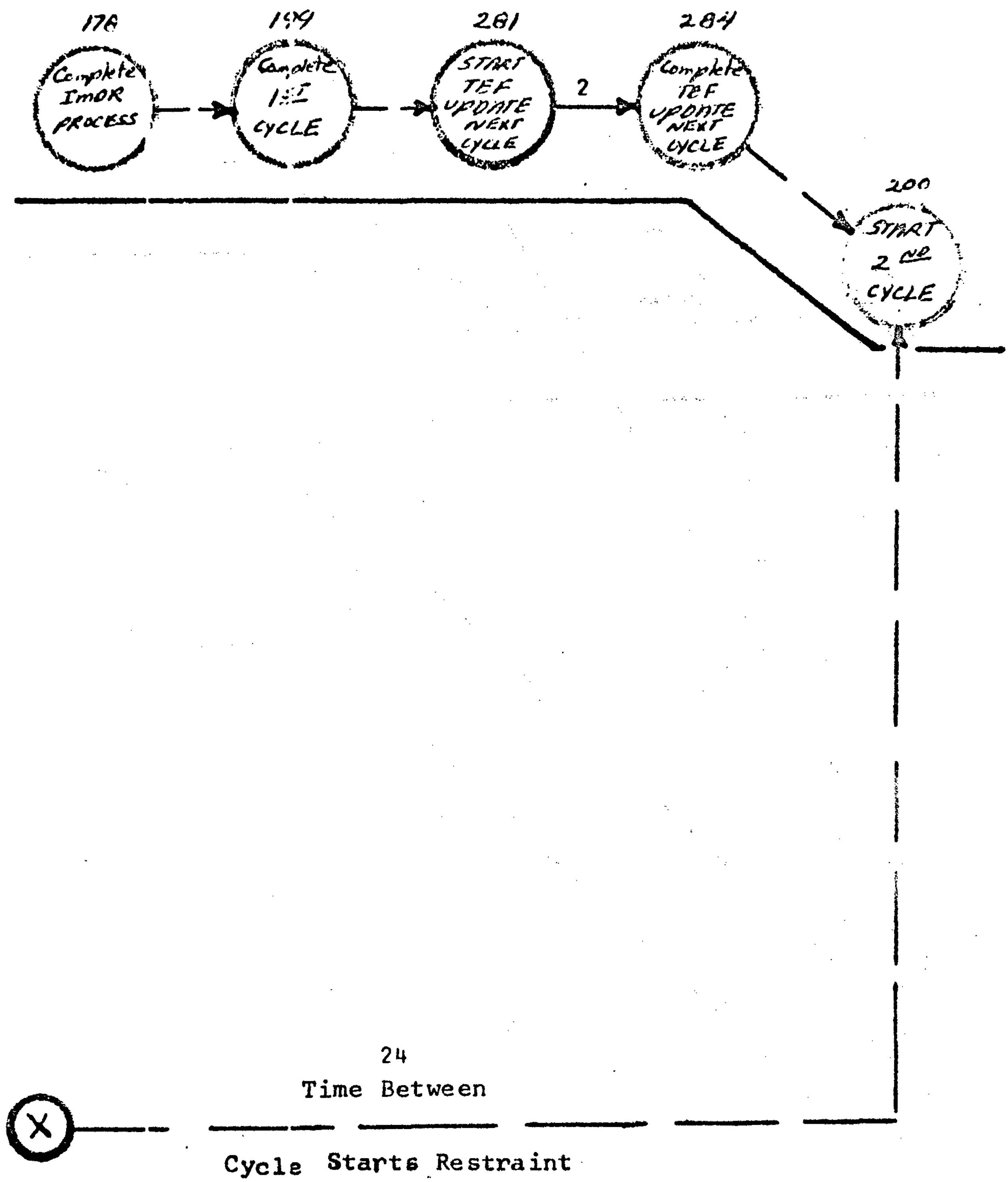
78
Complete TMOR PROCESS
181
START TEF UPDATE NEXT CYCLE
2
184
Complete TEF UPDATE NEXT CYCLE
99
Complete Initializing of PROCESS
100
START 1ST CYCLE
X



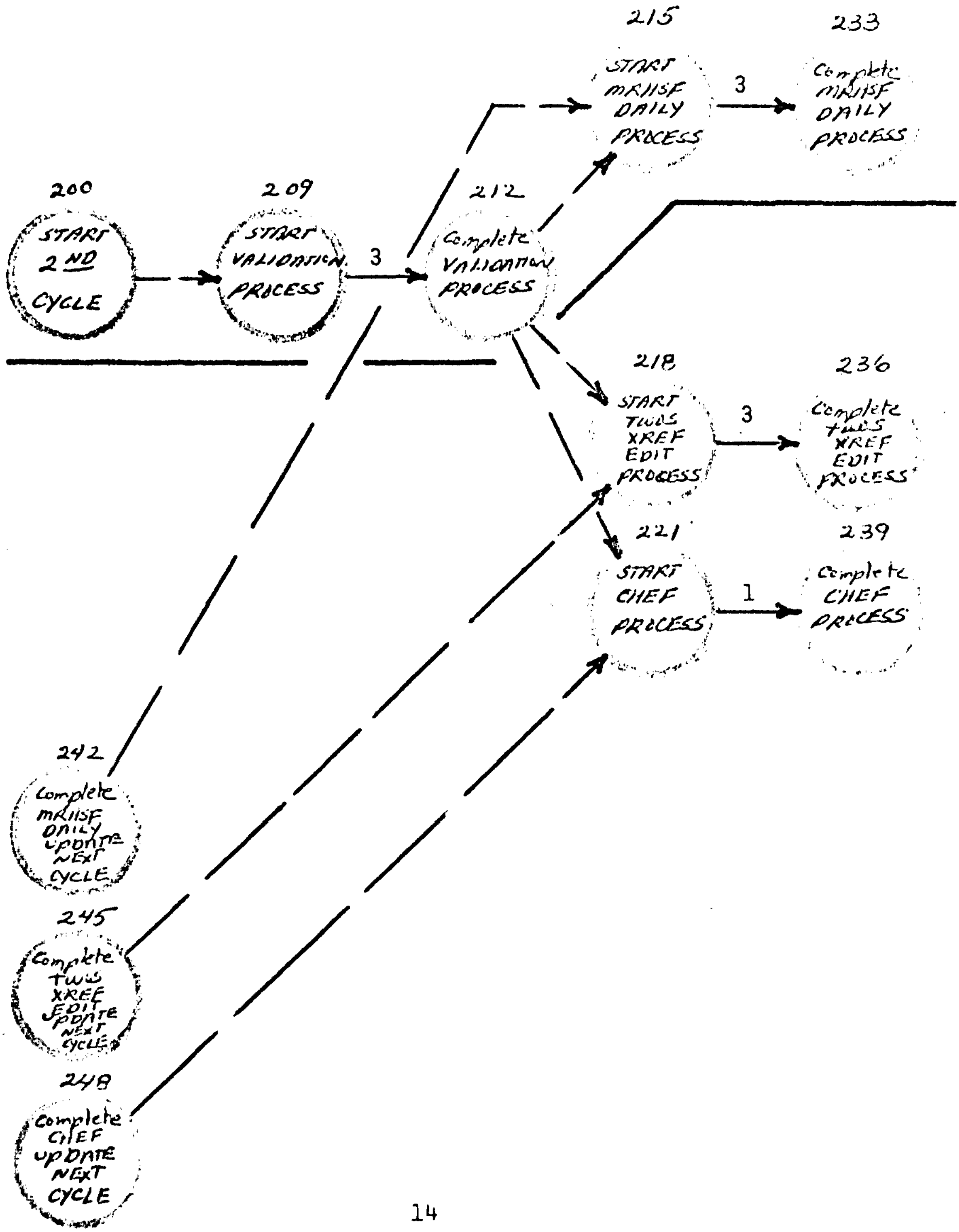
100
START
1 ST
CYCLE
109
START
VALIDATION
PROCESS
3
112
Complete
VALIDATION
PROCESS
115
START
MRHSF
DAILY
PROCESS
3
133
Complete
MRHSF
DAILY
PROCESS
118
START
TWOS
XREF
EDIT
PROCESS
3
136
Complete
TWOS
XREF
EDIT
PROCESS
121
START
CHEF
PROCESS
1
139
Complete
CHEF
PROCESS
142
Complete
MRHSF
DAILY
UPDATE
NEXT
CYCLE
224
START
MRHSF
DAILY
UPDATE
NEW
CYCLE
3
242
Complete
MRHSF
DAILY
UPDATE
NEXT
CYCLE
145
Complete
TWOS
XREF
EDIT
UPDATE
NEXT
CYCLE
227
START
TWOS
XREF
EDIT
UPDATE
NEXT
CYCLE
3
245
Complete
TWOS
XREF
EDIT
UPDATE
NEXT
CYCLE
148
Complete
CHEF
UPDATE
NEXT
CYCLE
230
START
CHEF
UPDATE
NEXT
CYCLE
1
248
Complete
CHEF
UPDATE
NEXT
CYCLE


175
Complete
MSP
UPDATE
NEXT
CYCLE
251
START
MSP
UPDATE
NEXT
CYCLE
154
START
MSP
PROCESS
4
157
Complete
MSP
PROCESS
133
Complete
DAILY
PROCESS
160
START
PROCESS

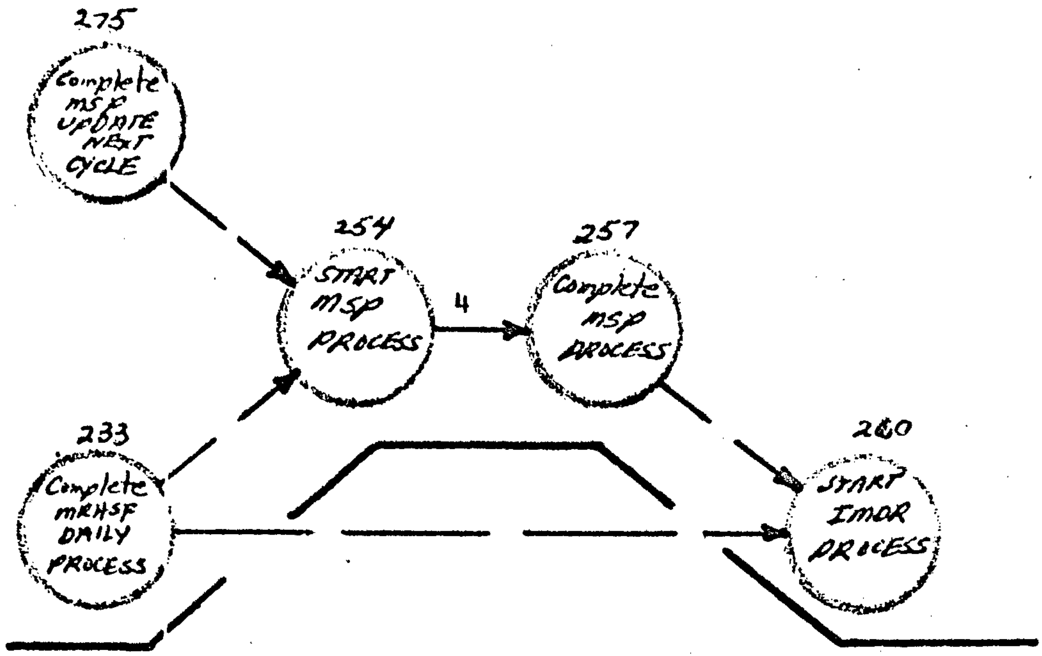

251
START MSF UPDATE NEXT CYCLE
4
275
Complete MSP UPDATE NEXT CYCLE
163
START IMOR PROCESS MACH I
14
169
Complete IMOR PROCESS MACH I
160
START IMOR PROCESS
178
Complete IMOR PROCESS
166
START IMOR PROCESS MACH II
12
172
Complete IMOR PROCESS MACH II
136
Complete TWCS XREF EDIT PROCESS
139
Complete CHEF PROCESS

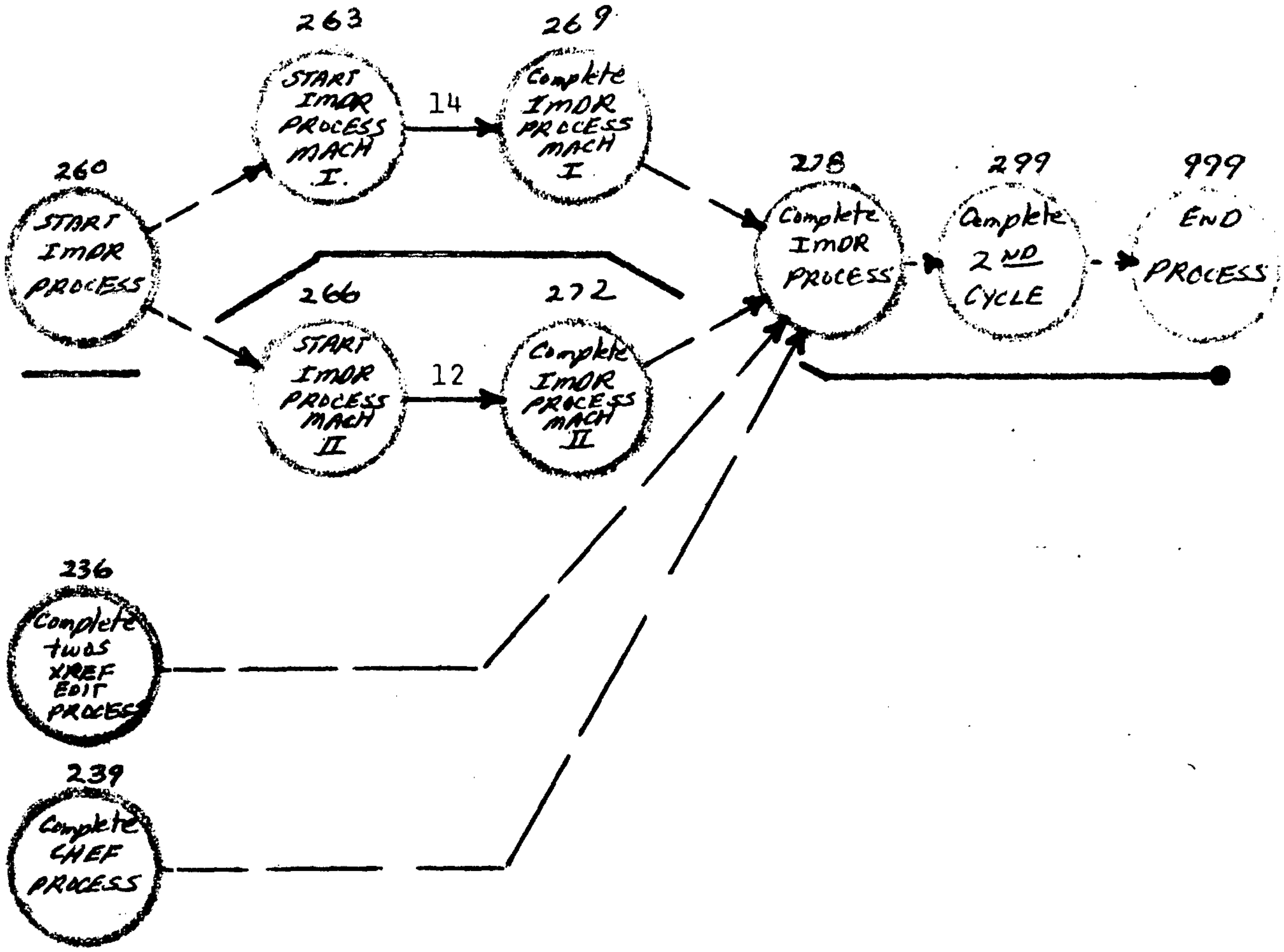


178
Complete IMOR PROCESS
Complete 1ST CYCLE
281
START TEF UPDATE NEXT CYCLE
2
284
Complete TEF UPDATE NEXT CYCLE
200
START 2ND CYCLE
24
Time Between
Cycle Starts Restraint



200
START 2 ND CYCLE
209
START VALIDATION PROCESS
3
212
Complete VALIDATION PROCESS
215
START MRIISF DAILY PROCESS
3
233
Complete MRIISF DAILY PROCESS
218
START TWIS XREF EDIT PROCESS
3
236
Complete TWIS XREF EDIT PROCESS
221
START CHEF PROCESS
1
239
Complete CHEF PROCESS
242
Complete MRIISF DAILY UPDATE NEXT CYCLE
245
Complete TWIS XREF EDIT UPDATE NEXT CYCLE
248
Complete CHEF UPDATE NEXT CYCLE


275
Complete MSP UPDATE NEXT CYCLE
254
START MSP PROCESS
4
257
Complete MSP PROCESS
233
Complete MRHSF DAILY PROCESS
260
START IMOR PROCESS



260
START IMOR PROCESS
263
START IMOR PROCESS MACH I.
14
269
Complete IMOR PROCESS MACH I
266
START IMOR PROCESS MACH II
12
272
Complete IMOR PROCESS MACH II
278
Complete IMOR PROCESS
299
Complete 2 ND CYCLE
999
END PROCESS
236
Complete twas XREF EDIT PROCESS
239
Complete CHEF PROCESS

III. Example of the Critical Path Method Procedure (cont...)

c. Tabulation of Analysis Results (Step 5b)

The following input data was subjected to a CPM Analysis by use of a computer time-sharing terminal. The output data from the analysis consisted of the critical path(s), activity (i,j), activity duration (DUR), earliest start time (ES), earliest finish time (EF), latest start time (LS), latest finish time (LF), total float-slack time (TF), Level (LEV), cost when applicable ($).

(1) Input Data

```
1,6,0,00,6,9,0,00,9,12,2,00,12,15,0,00,
12,15,0,00,12,21,0,00,12,124,0,00,12,127,0,00,
12,130,0,00,15,33,0,00,18,30,3,00,21,30,1,00,
124,142,3,00,127,145,7,00,130,148,1,00,33,151,0,00,
33,54,0,00,33,39,0,00,30,75,0,00,39,75,0,00,
142,115,0,00,145,115,0,00,148,121,0,00,151,175,4,00,
54,57,4,00,57,60,0,00,60,63,0,00,60,66,0,00,
63,69,14,00,66,72,12,00,69,75,0,00,72,75,0,00,
175,154,0,00,75,151,0,00,151,154,0,00,154,[illegible],0,00,
96,100,0,00,100,103,0,00,100,200,24,00,105,112,2,00,
112,115,0,00,112,118,0,00,112,121,0,00,112,224,0,00,
112,227,0,00,112,230,0,00,115,133,3,00,115,136,3,00,
121,139,1,00,224,242,3,00,227,245,3,00,230,248,1,00,
133,251,1,00,133,154,0,00,133,160,0,00,136,172,0,00,
139,178,0,00,242,215,0,00,245,218,0,00,248,221,0,00,
251,275,4,00.154,157,4,00,157,160,0,00,160,163,0,00,
160,166,0,00,163,169,14,00,166,172,12,00,169,175,0,00,
172,178,0,00,275,254,0,00,178,199,0,00,199,231,0,00,
231,234,2,00,234,200,0,00,200,209,0,00,209,212,2,00,
212,215,0,00,215,233,3,00,218,236,3,00,221,239,1,00,
233,254,0,00,233,260,0,00,236,278,0,00,239,278,0,00,
254,257,4,00,257,260,0,00,260,263,0,00,260,266,0,00,
263,269,14,00,266,272,12,00,269,278,0,00,272,278,0,00,
278,299,0,00,299,999,0,00,
1,999,-1,0,
```

III. Example of the Critical Path Method Procedure (cont...)

(2) Output Results

CPM2 13:08 TUE. 03/04/69.

DARTMØUTH ALGØL.

WHAT CØL. FØR SØRT AND HØW MANY ACT.?9,0

WHAT CØL. FØR SØRT AND HØW MANY ACT.?8,94

PRØJECT DURATIØN: 73 TØTAL CØST: $ 0

CRIT	I	J	DUR	EC	EF	LS	LF	TF	LEV	$
*	1	6	0	0	0	0	0	0	1	0
*	6	9	0	0	0	0	0	0	2	0
*	9	12	2	0	2	0	2	0	3	0
*	12	15	0	2	2	2	2	0	4	0
*	15	33	3	2	5	2	5	0	5	0
*	33	54	0	5	5	5	5	0	6	0
*	54	57	4	5	9	5	9	0	7	0
*	57	60	0	9	9	9	9	0	8	0
*	60	63	0	9	9	9	9	0	9	0
*	63	69	14	9	23	9	23	0	10	0
*	69	73	0	23	23	23	23	0	11	0
*	73	131	0	23	23	23	23	0	12	0
*	131	134	2	23	25	23	25	0	13	0
*	134	99	0	25	25	25	25	0	14	0
*	99	100	0	25	25	25	25	0	15	0
*	100	109	0	25	25	25	25	0	16	0
*	109	112	2	25	27	25	27	0	17	0
*	112	115	0	27	27	27	27	0	18	0
*	115	133	3	27	30	27	30	0	19	0
*	133	154	0	30	30	30	30	0	20	0
*	154	157	4	30	34	30	34	0	21	0
*	157	160	0	34	34	34	34	0	22	0
*	160	163	0	34	34	34	34	0	23	0
*	163	169	14	34	48	34	48	0	24	0
*	169	178	0	48	48	48	48	0	25	0
*	178	199	0	48	48	48	48	0	26	0
*	199	231	0	48	48	48	48	0	27	0
*	231	234	2	48	50	48	50	0	28	0
*	234	200	0	50	50	50	50	0	29	0
*	200	209	0	50	50	50	50	0	30	0
*	209	212	2	50	52	50	52	0	31	0
*	212	215	0	52	52	52	52	0	32	0
*	215	233	3	52	55	52	55	0	33	0
*	233	254	0	55	55	55	55	0	34	0
*	254	257	4	55	59	55	59	0	35	0
*	257	260	0	59	59	59	59	0	36	0
*	260	263	0	59	59	59	59	0	37	0
*	263	269	14	59	73	59	73	0	38	0
*	269	273	0	73	73	73	73	0	39	0
*	273	299	0	73	73	73	73	0	40	0
*	299	999	0	73	73	73	73	0	41	0

III. Example of the Critical Path Method Procedure (cont...)

(2) Output Results (cont...)

166	200	24	25	49	26	50	1	16	0
60	66	0	9	9	11	11	2	9	0
66	72	12	9	21	11	23	2	10	0
72	78	0	21	21	23	23	2	11	0
160	166	0	34	34	36	36	2	23	0
166	172	12	34	46	36	48	2	24	0
172	178	0	46	46	48	48	2	25	0
260	266	0	59	59	61	61	2	37	0
266	272	12	59	71	61	73	2	38	0
272	278	0	71	71	73	73	2	39	0
33	60	0	5	5	9	9	4	6	0
133	160	0	30	30	34	34	4	20	0
233	260	0	55	55	59	59	4	34	0
12	18	0	2	2	20	20	18	4	0
18	36	3	2	5	20	23	18	5	0
36	78	0	5	5	23	23	18	6	0
112	118	0	27	27	45	45	18	18	0
118	136	3	27	30	45	48	18	19	0
136	178	0	30	30	48	48	18	20	0
12	21	0	2	2	22	22	20	4	0
21	39	1	2	3	22	23	20	5	0
39	78	0	3	3	23	23	20	6	0
112	121	0	27	27	47	47	20	18	0
121	139	1	27	28	47	48	20	19	0
133	251	1	30	31	50	51	20	20	0
139	178	0	28	28	48	48	20	20	0
251	275	4	31	35	51	55	20	21	0
275	254	0	35	35	55	55	20	22	0
33	151	0	5	5	26	26	21	6	0
151	175	4	5	9	26	30	21	7	0
175	154	0	9	9	30	30	21	8	0
12	124	0	2	2	24	24	22	4	0
124	142	3	2	5	24	27	22	5	0
142	115	0	5	5	27	27	22	6	0
112	224	0	27	27	49	49	22	18	0
224	242	3	27	30	49	52	22	19	0
242	215	0	30	30	52	52	22	20	0
12	127	0	2	2	42	42	40	4	0
127	145	3	2	5	42	45	40	5	0
145	118	0	5	5	45	45	40	6	0
112	227	0	27	27	67	67	40	18	0
227	245	3	27	30	67	70	40	19	0
245	218	0	30	30	70	70	40	20	0
218	236	3	30	33	70	73	40	21	0
236	278	0	33	33	73	73	40	22	0
12	130	0	2	2	46	46	44	4	0
130	148	1	2	3	46	47	44	5	0
148	121	0	3	3	47	47	44	6	0
112	230	0	27	27	71	71	44	18	0
230	248	1	27	28	71	72	44	19	0
248	221	0	28	28	72	72	44	20	0
221	239	1	28	29	72	73	44	21	0
239	273	0	29	29	73	73	44	22	0

III. Example of the Critical Path Method Procedure (cont...)

(3) Summary of Pertinent Analysis Results Relevant to Routine File Maintenance

Activity	Description	Process Time	Earliest Start Time-Hr (ES)	Latest Start Time-Hr (LS)
124-142 224-242	MRHSF Daily Update Next Cycle	3	2 27	24 49
127-145 227-245	TWOS XREF Edit Update Next Cycle	3	2 27	42 67
130-148 230-248	CHEF Update Next Cycle	1	2 27	46 71
151-175 251-275	MSP Update Next Cycle	4	5 31	26 51
181-184 281-284	TEF Update Next Cycle	2	23 48	23 48

III. Example of the Critical Path Method Procedure (cont...)

d. Establish a Feasible Scheduling Sequence (Steps 7-8)

There are many techniques and procedures available for sequencing jobs on machines in the literature. The state-of-the-art is such today that none of them are sufficient for obtaining the optimum sequence for scheduling jobs on a computer nor are they practical for implementation. Therefore, the following technique is presented for the sake of demonstration rather than recommendation. It is a fairly simple technique but will require evaluation before it should be implemented. The technique was developed by Hedgeson and Bernie*.

The technique concerns itself with the balancing of assembly operations in order to keep the unassigned or idle time required to complete an assembly operation to a minimum. Two formulations of the problem are presented in the referenced technical paper:

(1) Minimize the number of work stations for a given cycle time.

(2) Minimize the cycle time for a given number of work stations.

The technique for the first formulation is the one that is demonstrated in the following. The Algorithm (set of rules) for this technique are included in Appendix A.

---

*Reference: Hedgeson, W.B. and Bernie, D.P., "Assembly Line Balancing Using the Ranked Positional Weight Technique", The Journal of Industrial Engineering, Volume XII, No. 6, pp 394-398, 1961

III. Example of the Critical Path Method Procedure (cont...)

(1) Establish a table depicting by activity, the latest finish time (LF), subsequent sequence time (MAX Subsequent Sequence Time - LF), Process Time (DUR), and activities that must immediately precede it (see table 1).

(2) Reorder preceding data table in order of decreasing "subsequent-sequence time" (see table 2).

(3) Determine a desirable cycle time. Since in the current example, there are 143 computer hours required to complete two cycles and assuming four computers available, an optimum cycle time would be 143/(4)(2)=143/8=18 Hours. A review of table 1 reveals that the activity with the longest duration has a duration of 14 hours, so a cycle time of 14 hours is the minimum that can currently be achieved with this data set. Since the optimum cycle time of 18 hours is greater than 14 hours, the maximum activity duration time, the 18 hours can be used when assigning the activities to the computer.

If the maximum activity duration time had been larger than the optimal cycle time, then the maximum activity duration time of 14 hours would have to be used as the lower limit for cycle time values when assigning activities to the computer.

In the following, a possible assignment and sequence of operations was determined assuming a 22 hour and 18 hour cycle time. The solutions have been presented both in a tabular form and also a Gantt Chart.

TABLE 1

Latest Finish Time, Subsequent Sequence Time, Process Time, and Preceding Activities.

Activity	Activity Number	Latest Finish Time (HR)	Subsequent Sequence Time	Process Time (HR)	Activities that Must Immediately Precede
9-12	9	2	71	2	-
15-33	15	5	68	3	9
18-36	18	23	50	3	9
21-39	21	23	50	1	9
54-57	54	9	64	4	15
63-69	63	23	50	14	54
66-72	66	23	50	12	54
109-112	109	27	46	2	131
115-133	115	30	43	3	124, 109
118-136	118	48	25	3	109, 127
121-139	121	48	25	1	109, 130
124-142	124	27	46	3	9
127-145	127	45	28	3	9
130-148	130	47	26	1	9
151-175	151	30	43	4	15
154-157	154	34	39	4	115, 151
163-169	163	48	25	14	154
166-172	166	48	25	12	154
181-184	181	25	48	2	63, 66, 18, 21
209-212	209	52	21	2	281
215-233	215	55	18	3	224, 209
218-236	218	73	0	3	209, 227
221-239	221	73	0	1	209, 230
224-242	224	52	21	3	109
227-245	227	70	3	3	109
230-248	230	72	1	1	109
251-275	251	55	18	4	115
254-257	254	59	14	4	215, 251
263-269	263	73	0	14	254
266-272	266	73	0	12	254
281-284	281	50	23	2	163, 166, 118, 121
			TOTAL:	143 HR	

III. Example of the Critical Path Method Procedure (cont...)

(4) Following the rules outlined in the Algorithm, reference Appendix A, and referring to Table 2, the activities are assigned to the computers. Essentially, attention is given to the operations that must precede and activities having the greatest subsequent processing time are assigned first. The solutions, possible assignment and sequence of operations, are presented on Tables 3 and 4 for the 18 hour cycle time and on Tables 5 and 6 for the 22 hour cycle time.

TABLE 2

Subsequent Sequence Times and Preceding Activities in Order of Decreasing Subsequent Sequence Time.

Activity Number	Subsequent Sequence Time (HR)	Process Time (HR)	Activities That Must Immediately Precede
9	71	2	-
15	68	3	9
54	64	4	15
18	50	3	9
21	50	1	9
63	50	14	54
66	50	12	54
181	48	2	63, 66, 18, 21
109	46	2	181
124	46	3	9
115	43	3	124, 109
151	43	4	15
154	39	4	115, 151
127	28	3	9
130	26	1	9
118	25	3	109, 127
121	25	1	109, 130
163	25	14	154
166	25	12	154
281	23	2	163, 166, 118, 121
209	21	2	281
224	21	3	109
215	18	3	224, 209
251	18	4	115
254	14	4	215, 251
227	3	3	109
230	1	1	109
218	0	3	209, 227
221	0	1	209, 230
263	0	14	254
266	0	12	254

TABLE 3

Possible Assignment and Sequence of Activities

(18 Hours Cycle Time)

Station Number/ Computer (Number)	Activities Assigned	Time (Hours) Assigned - Remaining (-)
I (I)	9, 15, 54, 18, 21, 124, 130	2, 3, 4, 3, 1, 3, 1 (16), (13), (9), (6), (5), (2), (1)
II (II)	63, 151	14, 4 (4), (0)
III (III)	66, 181, 109, 121, 230	12, 2, 2, 1, 1 (6), (4), (2), (1), (0)
IV (I)	115, 154, 127, 118, 224	3, 4, 3, 3, 3 (15), (11), (8), (5), (2)
V (II)	163, 251	14, 4 (4), (0)
VI (III)	166, 281, 209, 221	12, 2, 2, 1 (6), (4), (2), (1)
VII (I)	215, 254, 227, 218	3, 4, 3, 3 (15), (11), (8), (5)
VIII (II)	263	14 (4)
IX (III)	266	12 (6)

TABLE 4

Possible Assignment and Sequence of Activities

(18 Hours Cycle Time)

GANTT CHART

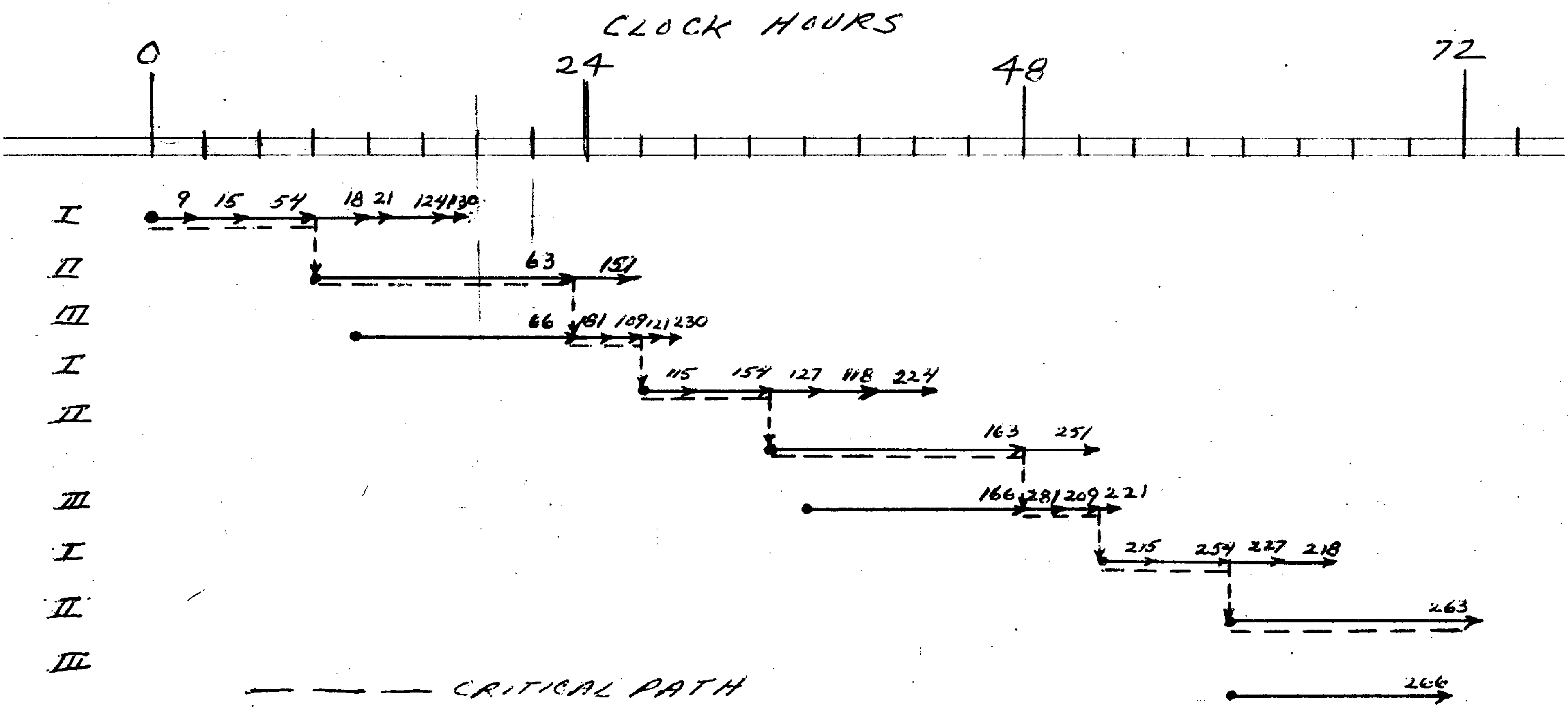


TABLE 5

Possible Assignment and Sequence of Activities

(22 Hours Cycle Time)

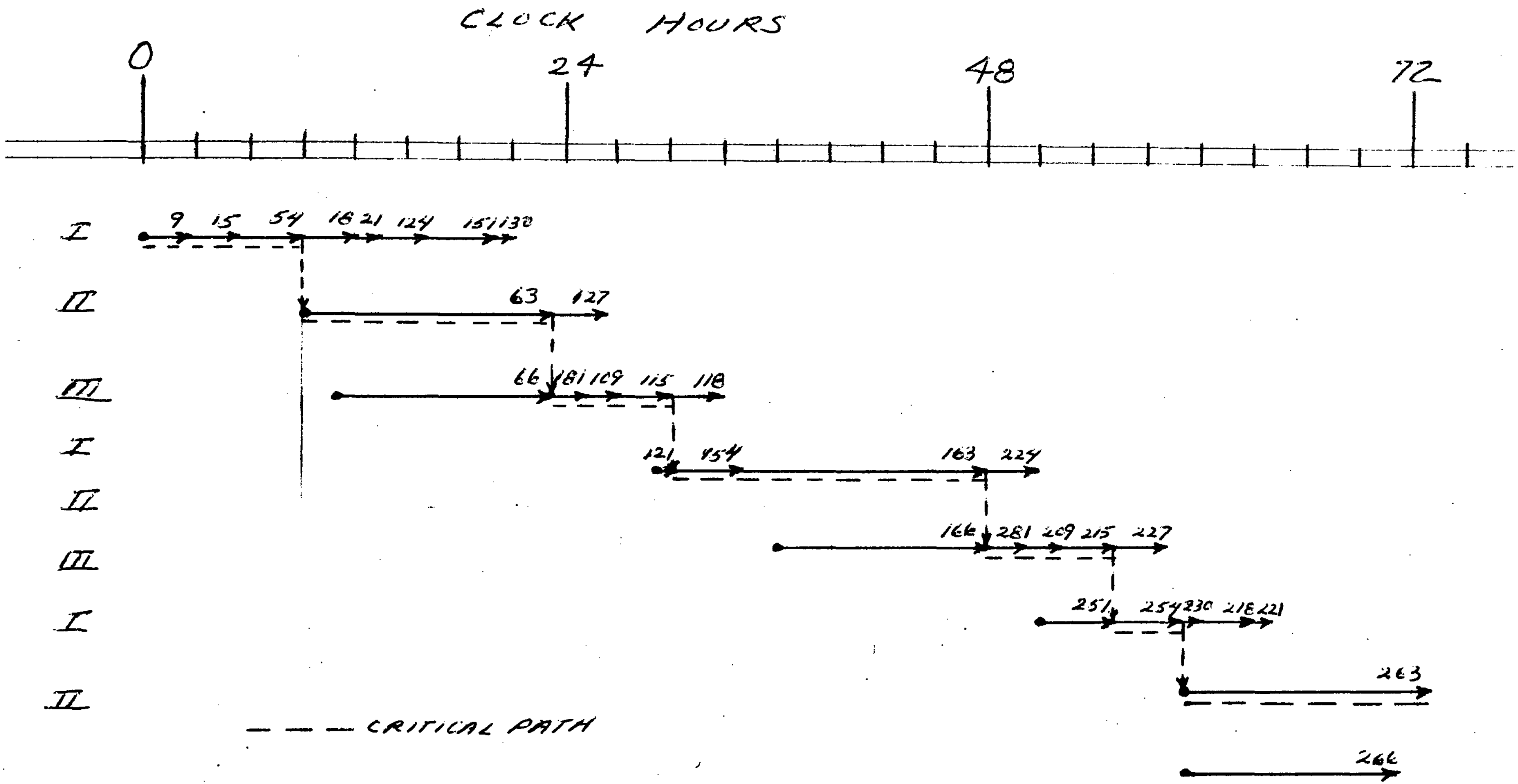
Station Number/ Computer (Number)	Activities Assigned	Time (Hours) Assigned - Remaining (-)
I (I)	9, 15, 54, 18, 21, 124 151, 130	2, 3, 4, 3, 1, 3 (20), (17), (13), (10), (9), (6) 4, 1 (2), (1)
II (II)	63, 127	14, 3 (8), (5)
III (III)	66, 181, 109, 115, 118	12, 2, 2, 3, 3 (10), (8), (6), (3), (0)
IV (I)	121, 154, 163, 224	1, 4, 14, 3 (21), (17), (3), (0)
V (II)	166, 281, 209, 215, 227	12, 2, 2, 3, 3 (10), (8), (6), (3), (0)
VI (III)	251, 254, 230, 218, 221	4, 4, 1, 3, 1 (18), (14), (13), (10), (9)
VII (I)	263	14 (8)
VIII (II)	266	12 (10)

TABLE 6

Possible Assignment and Sequence of Activities

(22 Hours Cycle Time)

GANTT CHART



III. Example of the Critical Path Method Procedure (cont...)

c. Interpretation and Evaluation (Steps 8 and 9)

The interpretation and evaluation has been deferred at this time until the above technique has been applied to a real network with real data. Some of the performance parameters under consideration for such an evaluation are as follows:

(1) <u>Performance Parameters</u>

Quantity of late jobs

Total late time

Total early time (slack time)

Total process time

Total maintenance time

Maximum late time per late job

Minimum late time per late job

Quantity of on-time jobs

Total quantity jobs

(2) Optimization Criteria

Many criteria are possible for optimization. The performance, of course, will vary according to which criteria is optimized. A few examples of possible criteria are as follows:

(a) Minimize quantity of late jobs.

(b) Minimize quantity of high priority jobs that are late.

(c) Minimize total late time for jobs.

(d) Minimize quantity of jobs on a computer. (Essentially will minimize scheduled idle time between job change-overs).

III. Example of the Critical Path Method Procedure (cont...)

(e) Minimize quantity of late jobs first and minimize total late time for jobs second.

(f) Minimize "make-span": Determine a schedule that causes the latest-finishing job to be completed at the earliest possible time.

(g) Given n jobs, m machines, for each machine there is a maximum available time. What jobs should be assigned to which machine in order to minimize the idle time on each of the machines. Assume certain jobs can be processed only on certain (not all) machines.

CRITICAL PATH METHOD
CPM
(Project Planning and Scheduling)

IV. Glossary of Relevant Terms, Concepts, and Techniques

Gantt Chart: Planning and scheduling are presented simultaneously and are inseparable.

CPM: Planning and scheduling can be done independently.

Planning: The act of stating what activities must occur in a project and in what order these activities must take place.

Scheduling: The act of producing project time tables in consideration of the plan and costs.

Planning: Concerns itself with the structual characteristics of a project. It describes the precedence among project jobs, operations, or activities and is represented and facilitated by the use of a graphic technique, the arrow diagram or network representation.

Network: Is a graphical representation of a project plan, showing the interrelationships of the various activities.

Cyclical Network: Is a network which has a number of cycles or group of activities. Such a network can be composed of several condensed networks.

Detailed Network: Is a network in which activities are defined on a level of considerable detail thereby resulting in a relatively large network.

Condensed Network: Is a summarized version of a detailed network.

Glossary of Relevant Terms, Concepts, and Techniques (cont...)

Activity: Is a task or job within a project that cannot begin until certain other activities are completed. They involve a time - or other resource consuming element of the project.

Event: Is the beginning or ending of an activity.

Activity on Node Network: Is a network in which the activities are graphically represented by the nodes. The arrows are used to represent only the dependency relationships among the nodes.

Event Oriented Network: Is a network in which the activities are graphically represented by arrows. The nodes represent either start or complete events. At merge and burst points, dummy activities are introduced in the network to avoid ambiguities.

Critical Activity: Is an activity that if delayed will affect all other activities following it and will thus affect the completion of the overall project. If they are not completed at given points in time an overall project delay is incurred. (They have no float).

Critical Path(s): One or more contiguous path(s) of critical activities through any project arrow diagram.

Float: A certain amount of leeway or float is associated with all the non-critical activities.

Timely Control: Of a project requires awareness of both the critical path(s) and the amount of leeway or float available for each activity.

Types of Float: Three types can be identified: total float, free float, and independent float.

Total Activity Stock (or Float): It is the amount of time that the activity completion time can be delayed without affecting the earliest start or occurrence time of any activity or event on the network critical path. It is computed by taking the latest allowable time of the activity's successor event minus the earliest finish time of the activity in question. (The largest of the three floats).

Free activity Slack (or Float): It is the amount of time that the activity completion time can be delayed without affecting the earliest start or occurrence time of any other activity or event in the network. Computed by taking the earliest expected time of the activity's successor event minus the earliest finish time of the activity in question.

Independent Float: Is the leeway available no matter where preceeding or succeeding activities are placed within their intervals of float.

Ready-Time: The earliest time at which processing can begin.

Processing-Time: The amoutn of time required on the machine.

Due-Time: The time by which completion is desired.

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APPENDIX A

ALGORITHM

To Minimize the Number of Work Stations for a Given Cycle Time

(Hedgeson and Bernie)

1. Select the work unit with the highest positional weight and assign it to the first work station. (It is assumed that one would not try to balance the line to a cycle time smaller than the time of the largest work element on the line, therefore the first assignable work unit can always be assigned to an empty work station.)

2. Calculate the unassigned time for the work station by calculating the cumulative time of all work units assigned to the station and subtract this sum from the cycle time.

3. Select the work unit with the next highest positional weight and attempt to assign it to the work station after making the following checks:

a. Check the list of already assigned work units. If the "immediate precedent" work unit has been assigned, precedence will not be violated; preceed to step 3b. If the "immediate precedent" has not been assigned proceed to step 4.

b. Compare the work unit time with the unassigned time. If the work unit time is less than the work station unassigned time, assign the work unit and recalculate unassigned time. If the work unit time is greater than the unassigned time, proceed to step 4.

4. Continue to select, check, and assign if possible until one of two conditions has been met:

a. All work units have been assigned.

b. No unassigned work unit remains that can satisfy both the precedence requirement and the "less than the unassigned time" requirement.

5. Assign the unassigned work unit with the highest positional weight to the second work station, and proceed through the preceding steps in the same manner.

6. Continue assigning work units to work stations until all work units have been assigned. At that time a solution to the assembly line balancing problem will have been found.

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13. ABSTRACT

This report presents by example the application of the critical path method (CPM) for the planning and scheduling of jobs on a computer. It provides a step-by-step preparation and analysis of a network representation of a computer system application. Also, included is a glossary of relevant terms and a fairly comprehensive bibliography on the subject of CPM/PERT, scheduling and sequencing.

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